GUIDELINES FOR THE DESIGN OF BEACH DEBRIS SURVEYS

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ABSTRACT

Beach surveys give valuable information as to the types, quantities, and sources of marine debris floating at sea. With the passage of Annex V of MARPOL, however, a decrease in marine debris needs to be detected to demonstrate the effectiveness of mitigating legislation. In order to detect a decrease in marine debris washed ashore, beach survey methodology will need to be standardized. Standardization of survey methods based upon the authors' experience in Alaska is discussed, as is the design of beach surveys to detect between 30 and 50% decreases in the amount of marine debris washed ashore after 5 years, with 95% confidence and power of 80%. Preliminary findings suggest that the number of surveys of a given beach needed to detect a 50% change will be large (bimonthly surveys for 5 years). Annual surveys have low power for detecting a 50% decrease after 5 years, although this result depends on estimates of within-beach variability. Hopefully, this proposal will lead to a discussion of standardized methodology for marine debris beach surveys and the detection of change.

INTRODUCTION

Plastics and other synthetic materials discarded at sea constitute "marine debris" and are now recognized internationally as a form of marine pollution. There is no consensus, however, on how to monitor marine debris after it has washed ashore. Standardized protocols for monitoring other

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pollutants have been established; examples are tar ball pollution (IOCARIBE 1980) and chemical pollution (Kullenberg 1986). Developing standardized methods will make planning easier and comparison between areas more meaningful.

One of the easiest and most cost-effective methods for arriving at an index of marine debris pollution is the beach survey (Dixon and Dixon 1981; Merrell 1985). The use of beach surveys as indices of floating marine debris, however, requires planned surveys with a clear statement of objectives and assumptions.

This paper has two objectives: (1) to outline the steps involved in planning a beach survey, and (2) to consider two different sampling designs for detecting a decrease in marine debris following the implementation of MARPOL Annex V.

METHODS

A literature review was conducted to identify all published papers on the subject of beach surveys of marine debris excluding tar. Tar pollution was excluded because of the widespread use of standardized techniques to census tar balls on beaches (IOCARIBE 1980). Studies were divided into two groups. The first group focused on describing marine debris on the study area. The second focused on using the beach survey as an indicator of floating marine debris. Next, for all studies, we checked whether the entire beach was surveyed or only portions (transects) of it. Studies were then put into a conceptual framework proposed for planning beach surveys.

The design of surveys to investigate the effect of mitigating legislation (MARPOL Annex V) to reduce the input of debris into the ocean was based on intervention analysis of time series (Hipel et al. 1978; Lettenmaier et al. 1978; Barnard et al. 1985). We also considered a repeated measures 1-factor experimental design (Myers 1972) as a second design.

First, we were interested in determining the sample size (number of surveys) needed over 5 years to detect a 30 to 50% change in the amount of marine debris with power (probability of detecting the change) of 0.80 and an alpha of 0.05. An estimate of the variance between years was based on data in Merrell (1985) for Amchitka Island 1972-74. This estimate was used to translate the percentage change into trend or standard deviation ratios needed to use the graphs in Lettenmaier et al. (1978). We also considered the effect on power of changing sample sizes in detecting a standardized difference of 1 standard deviation (45% change) over 5 years for alpha = 0.05 and alpha = 0.20. In all cases, gamma, the ratio of number of samples before mitigation to total number of samples, was 0.15 or 0.20. Lettenmaier et al. (1978) showed that gamma should be small for the linear intervention model we used.

Secondly, we were interested in the power associated with doing annual surveys for 5 years and detecting a change between 20 and 50% and an alpha of 0.10. Power was taken from Cohen (1977). For Amchitka Island, an

estimate of within-beach variability was calculated from Merrell (1980) for 1972-74 and a mean of 361 pieces of debris per kilometer (Merrell 1984) was used to translate percent change into pieces of debris per kilometer. For the Yakutat area, an estimate of within-beach variability was calculated from data collected 1984-87, and a mean of 205.95 pieces of debris per kilometer was used to translate percent change into pieces of debris per kilometer.

RESULTS

General Beach Survey Design Considerations

The process of beach survey design is summarized in Figure 1. From the published literature, most beach surveys have been short term (one-time surveys) and focused on a single study area (individual beaches) (Cundell 1973; Gregory 1977, 1978, 1983; Bigg 1982; Gregory et al. 1984; Neilson 1985; Willoughby 1986; Henderson et al. 1987; Center for Environmental Education 1988; Marine Plastic Debris Task Force 1988). This focus on the shoreline or beach has led to massive volunteer efforts to clean beaches with little or no reporting of data. These types of studies are valuable for cleaning beaches and gathering information on the types and composition of debris on various coastlines. But quantitative analysis of such data is restricted due to small sample sizes (an annual cleanup means that the sample size is 1) and missing data (especially where data are voluntarily reported).

Few studies stated that their objective was to use the beach debris surveys as an index of floating marine debris. Most studies using beach surveys as an index of oceanic debris were European (Dixon and Cooke 1977; Dixon and Dixon 1981; Shell UK 1985; Federal Republic of Germany 1986; Vauk and Schrey 1987). In the United States, the only published program using beach debris surveys as an index of marine debris is that of Merrell and Johnson in Alaska (Merrell 1980, 1984, 1985; Merrell and Johnson 1987; Johnson 1988; Johnson and Merrell 1988).

In all cases, a precise definition of the sampling unit is needed (Fig. 1). The natural unit is the entire beach from the water's edge to the seaward limit of terrestrial vegetation. In Alaska, most beaches surveyed are 1 km long (Merrell 1985). In England, Dixon and Dixon (1981) used transects, noting that there was too much debris to be totally counted. Where possible, we propose that the entire beach be the survey unit, with results standardized to length (e.g., debris per kilometer). In all cases, the same sampling units should be surveyed over time to minimize variability between surveys.

Before the actual sampling units are chosen, it is best to survey the area of interest to determine beach characteristics and debris distribution (Fig. 1). This is where massive volunteer cleanup efforts can be utilized to help plan the study. It is important to know substrate type, beach slope, prevailing winds, ease of access, and recreational use of the area (Dixon and Dixon 1981; Merrell 1985). Depending upon one's objective, all these factors can influence the choice of beach. Preferred beaches are

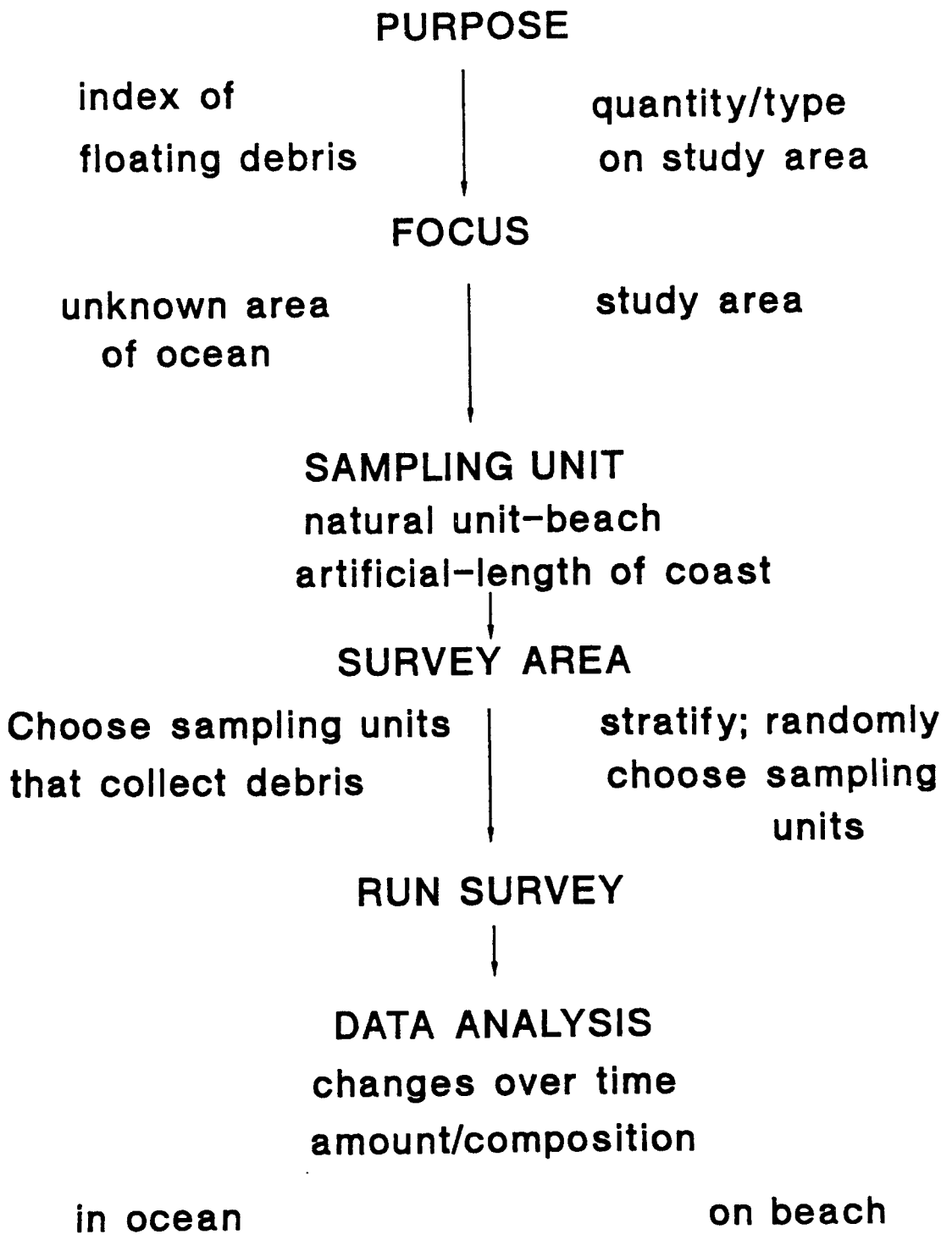

Figure 1.--Steps in the design of beach surveys.

moderate-to-steep sand or gravel beaches that are exposed to open ocean. Beaches should have 1 km of similar substrate and scope and be as far as possible from urban areas to minimize bias from local refuse.

Analysis of beach survey data depends on the purpose of the study as well as on the method of data collection. For example, Henderson et al. (1987) examined the distribution of net fragments on the beaches of the Northwestern Hawaiian Islands because they were interested in the location of the debris within the beach. Comparisons between years for beaches is possible with the following caveat. The common statistical tests such as t-tests and analysis of variance (Zar 1986) are not appropriate here because the same beaches are censused over time. The more appropriate techniques are paired-t tests, repeated measures analyses of variance, and their nonparametric equivalents (Conover 1980; Zar 1986). The use of time-series analysis is not appropriate because of the extremely low sample sizes usually found in these studies.

If the focus of the study is an index of floating marine debris, changes over time are of interest but the change is for an unknown area of ocean (Fig. 1). It is not appropriate to extrapolate to other beaches. Merrell (1980) stated that he had problems in extrapolating debris abundance to other beaches.

Beach Surveys as Indicators of Oceanic Debris

There are at least two important assumptions made when using beach surveys as indicators of floating marine debris (Ribic and Bledsoe 1986). The first assumption is that the debris at time t (the first sampling period) is not the same debris as that at time t+1 (the second sampling period). In other words, the same debris is not counted twice. The easiest way to fulfill this assumption is by clearing the beach of all surface debris after each survey (e.g., Cundell 1973; Shell UK 1985; Federal Republic of Germany 1986; Henderson et al. 1987). Sometimes this is not practical, especially when debris (e.g., trawl web) is partially buried or snarled on drift logs. In this case, debris can be tagged (Johnson 1988) for identification on later surveys. Tagging studies can provide information on minimum time between surveys as well as information on the loss and deposition rates of beach debris.

The second assumption is that the amount of debris on a beach is related to the amount of debris floating in an unknown area of ocean, and that this area is the same between surveys. In other words, the oceanic area swept onto the beach, when integrated over time, is the same between surveys. This is an important assumption if we want to conclude that a decrease in beach debris over time is due to mitigation measures and not due to a change between years in the area swept onto a beach. We would encourage a study of this assumption if beach surveys are to be useful as indicators of marine debris.

Detecting Change Due to Implementation of Legislation

We will model the potential impact of mitigating legislation (MARPOL Annex V) on the quantity of marine debris washed ashore with the simplest

model: A gradual linear decrease in marine debris over time.after the enactment of the law.

An extremely high survey effort over years will be needed to detect any decrease between 30 and 50% (Table 1). For a 45% decrease, a sample size of 180 translates into a beach survey 3 out of 4 weeks per month per year for 5 years. Detecting a 50% change would call for almost biweekly surveys every month for 5 years. However, the probability of detecting a 45% change is nil using annual surveys and is low using quarterly surveys (Table 2), i.e., the change would have to be so drastic that no statistics would be needed to notice it.

Using a different approach, we looked at treating annual debris counts as a repeated measure on beaches. An estimate of within-beach variability for Amchitka Island was 203 pieces of debris per kilometer. For the Yakutat area, an estimate of within-beach variability was 57 pieces of debris per kilometer. We then calculated minimum and maximum power for changes between 20 and 50% (Table 3) at alpha = 0.10. For Amchitka Island, the probability of detecting any change was low due to the high variability within beaches. Detecting a change of 50% with annual surveys has a power as low as 0.43-0.76 (Table 3). For the Yakutat area, however, the probability of detecting a change of 40% or more using annual surveys was between 0.50 and 0.95 (Table 3). This is due to the low within-beach variability.

DISCUSSION

We are just beginning to realize the magnitude of the marine debris problem. In order to quantitatively assess the problem, standardized beach surveys can be used. Standardization of methodology will make comparisons between areas easier and will ensure the validity of estimates.

It is important for researchers to state explicitly the objectives of their beach debris surveys. Whether or not a survey will be used as an index of floating marine debris affects the survey design from the choice of a particular sampling unit to the data collection and analysis.

A key assumption in using beach surveys to detect a difference due to mitigation is that the area of ocean swept onto the beach is constant between years. Firm conclusions about the effect of mitigating measures in decreasing floating marine debris based on beach debris surveys depend on this assumption. An attempt, therefore, should be made to evaluate its reasonableness.

Beach debris surveys are useful for determining the types and quantities of debris as well as entanglement potential. But the use of beach surveys to detect change with any degree of confidence and power will be more difficult. Preliminary sample size estimates are large for detecting a 50% decrease (power of 0.80; alpha = 0.05). Whether or not annual surveys will be adequate for detecting a 50% change (alpha = 0.10) depends on the estimate of within-beach variability. On Amchitka Island, variability on the same beach is large, and annual surveys will not be adequate for detecting a 50% decrease. In the Yakutat area, however,

Table 1.--Required sample sizes for detecting changes between 30 and 50% of beach debris for alpha = 0.05, power = 0.80, gamma = 0.20, and an estimate of variability = 103.429 pieces of debris per kilometer for a linear intervention model. n = total surveys spread over 5 years.

Percent change	Standardized difference	n
30	0.71	1,000
40	0.95	200
45	1.1	180
50	1.2	100

Table 2.--Probability of detecting a 45% change over 5 years (power) with a gamma = 0.15.

	Power	
	alpha	
n	0.05	0.20
5 (annual)	<0.10	<0.10
20 (quarterly)	0.20	0.45

Table 3.--Minimum and maximum power for a one-factor repeated measures design with alpha = 0.10 and k = 5 for detecting changes in beach debris between 20 and 50% for Amchitka Island and Yakutat beaches.

Percent change	Amchitka Island		Yakutat	
	Minimum	Maximum	Minimum	Maximum
20	0.14	0.22	0.20	0.34
30	0.22	0.38	0.33	0.63
40	0.30	0.58	0.52	0.87
45	0.46	0.67	0.61	0.94
50	0.43	0.76	0.71	>0.94

within-beach variability is lower, and annual surveys have a chance of detecting a 50% decrease over 5 years.

Designing a study to measure the impact of legislation to decrease the amount of marine debris will take more planning and a greater commitment of resources. As can be seen from our preliminary findings, sample sizes to detect a given change with stated precision will be large. An improved design could be constructed if we had better variance estimates of debris between beaches as well as within beaches, as well as consensus about the magnitude of the change we would like to detect. In addition, identifying and understanding factors that affect the deposition of debris will be critical in evaluating the success of mitigating legislation.

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REFERENCES

Barnard, J., W. Myers, J. Pearce, F. Ramsey, M. Sissenwine, and W. Smith.
1985. Surveys for monitoring changes and trends in renewable resources: Forests and marine fisheries. Am. Stat. 39:363-373.

Bigg, M. A.
1982. Sizes of scrap fishnet and plastic packing bands from western Vancouver Island during August-September 1982. Unpubl. manuscr.; available from Pacific Biological Station, Nanaimo, British Columbia V9R SK6, Canada. Background paper submitted to the 26th Annual Meeting of the Standing Scientific Committee, North Pacific Fur Seal Commission, March 28-29, 1983, Wash., D.C.

Center for Environmental Education.
1988. Texas coastal cleanup report. Center for Environmental Education, Wash., D.C., 105 p.

Cohen, J.
1977. Statistical power analysis for the behavioral sciences, revised edition. Acad. Press, N.Y., 474 p.

Conover, W. J.
1980. Practical nonparametric statistics. 2d ed., Wiley N.Y., 493 p.

Cundell, A. M.
1973. Plastic materials accumulating in Narragansett Bay. Mar. Pollut. Bull. 4:187-188.

Dixon, T. R., and A. J. Cooke.
1977. Discarded containers on a Kent beach. Mar. Pollut. Bull. 8:105-109.

Dixon, T. R., and T. J. Dixon.
1981. Marine litter surveillance. Mar. Pollut. Bull. 12:289-295.

Federal Republic of Germany.
1986. Degree and effects of environmental pollution of the German Bight and its coasts caused by synthetic material and other litter discarded by ships. Report submitted at the Thirteenth Meeting of the Standing Advisory Committee for Scientific Advice, Amsterdam, 10-14 March 1986, 15 p.

Gregory, M. R.
1977. Plastic pellets on New Zealand beaches. Mar. Pollut. Bull. 8:82-84.

1978. Accumulation and distribution of virgin plastic granules on New Zealand beaches. N.Z. J. Mar. Freshwater Res. 12:399-414.

1983. Virgin plastic granules on some beaches of eastern Canada and Bermuda. Mar. Environ. Res. 10:73-92.

Gregory, M. R., R. M. Kirk, and M. C. G. Mabin.
1984. Pelagic tar, oil, plastics and other litter in the surface waters of the New Zealand sector of the Southern Ocean and on Ross Dependency shores. N.Z. Antarct. Res. 6:12-28.

Henderson, J. R., S. L. Austin, and M. B. Pillos.
1987. Summary of webbing and net fragments found on Northwestern Hawaiian Islands beaches, 1982-86. Southwest Fish. Cent. Honolulu Lab., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI. Southwest Fish. Cent. Admin. Rep. H-87-11, 15 p.

Hipel, K. W., D. P. Lettenmaier, and A. I. McLeod.
1978. Assessment of environmental impacts, part one: Intervention analysis. Environ. Manage. 2:529-535.

IOCARIBE.
1980. CARIPOL manual for petroleum monitoring, October 1980. Conservation Department File No. 13/2/6.1. February 1981.

Johnson, S.
1988. Deposition of entanglement debris on Alaskan beaches. *In* D. L. Alverson and J. A. June (editors), Proceedings of the North Pacific Rim Fisherman's Conference on Marine Debris, Kailua-Kona, Hawaii, October 13-16, 1987, p. 64-94. Unpubl. rep. by Natural Resources Consultants, 4055 21st Ave. W., Seattle, WA 98188.

Johnson, S. W., and T. R. Merrell.
1988. Entanglement debris on Alaskan beaches, 1986. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/NWC-126, 26 p.

Kullenberg, G. (editor).
1986. The IOC programme on marine pollution. Mar. Pollut. Bull. 17:341-352.

Lettenmaier, D. P., K. W. Hipel, and A. I. McLeod.
1978. Assessment of environmental impacts, part two: Data collection. Environ. Manage. 2:537-554.

Marine Plastic Debris Task Force.
1988. Marine plastic debris action plan for Washington State. Washington State Department of Natural Resources, 45 p.

Merrell, T. R., Jr.
1980. Accumulation of plastic litter on beaches of Amchitka Island, Alaska. Mar. Environ. Res. 3:171-184.

1984. A decade of change in nets and plastic litter from fisheries off Alaska. Mar. Pollut. Bull. 15:378-384.

1985. Fish nets and other plastic litter on Alaska beaches. *In* R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii, p. 160-182. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFS-54.

Merrell, T. R., and S. W. Johnson.
1987. Surveys of plastic litter on Alaskan beaches, 1985. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/NWC-116, 21 p.

Myers, J. L.
1972. Fundamentals of experimental design. 2d ed. Allyn and Bacon, Inc., Boston, 465 p.

Neilson, J.
1985. The Oregon experience. *In* R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii, p. 154-159. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFS-54.

Ribic, C. A., and L. J. Bledsoe.
1986. Design of surveys for density of surface marine debris in the North Pacific. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Seattle, WA. NWAFC Processed Rep. 267, 69 p.

Shell UK.
1985. Braefoot Bay marine litter survey. Unpubl. rep. by Exploration and Production Environmental Affairs Department, 20 p.

Vauk, G. J. M., and E. Schrey.
1987. Litter pollution from ships in the German Bight. Mar. Pollut. Bull. 18:316-318.

Willoughby, N. G.
1986. Man-made litter on the shores of the Thousand Island Archipelago, Java. Mar. Pollut. Bull. 17:224-228.

Zar, J. H.
1986. Biostatistical analysis. Prentice Hall, Inc., Englewood Cliffs, 2d ed., NJ.